Large-Scale Metrology

Program Manager: Charles J Fronczek
Total FTE: 5.8
Total Funding: $983,525

Goal

To support the Manufacturing Engineering Laboratory's mission through measurements and measurement research on the scale of one meter or larger. These efforts are primarily focused in three areas; coordinate metrology with the linear axis coordinate measuring machines, coordinate metrology using frameless coordinate measuring systems (theodolites systems, tracking laser interferometer systems, or laser ranging systems) and machine tool metrology for emerging technologies such as the hexapod class of machine tools.

Program Objectives

FY2000

Develop the on-line systems to enhance support of external user interface within the National Advanced Manufacturing Testbed (NAMT) environment.

FY2001

Develop methodologies and artifacts for Coordinate Measuring Machine (CMM) calibration, performance evaluation, and task specific measurement uncertainty assessment, in support of national and international and U.S. Department of Defense (DOD) metrology standards.

Department of Defense Standardization Issues

Resolve outstanding standardization issues and complete DOD standard and procedures and field test at DOD site

FY2002

Develop methodologies and artifacts for laser based optical coordinate measurement systems (laser trackers) for calibration, performance evaluation, and to estimate measurement uncertainty in support of national and international metrology standards.

Laser Tracker Artifact

Work with U. S. industry to assess and develop a large-scale artifact that can be used for both performance evaluation and intercomparison of several different measurement technologies.

Laser Tracker Standard

Coordinate, under the auspices of the American Society of Mechanical Engineers (ASME), the B89.4.19 Optical Coordinate Systems group's effort to finalize the laser tracker standard and to shepherd it through the approval process.

FY2002

Develop the metrology system to characterize the positioning accuracy of the class of machining centers based upon the Stewart platform concept. The metrology system for enhanced positioning accuracy will be demonstrated on the Ingersoll vertical configuration of the Stewart platform concept.

Implementation of on-machine metrology system for NIST Hexapod

Implement, demonstrate, and refine on-machine metrology system for NIST Hexapod strut assembly.

FY2002

Provide high accuracy dimensional calibration of large scale artifacts and assist U. S. industry in solving unique and immediate large scale metrology problems while continuing to provide SP250 calibrations.

MARITECH

Develop and implement in cooperation with Atlantic Marine Holding, Inc. an advanced metrology systems in the ship repair and production facility in the Alabama Shipyard in Mobile, AL.

Measurement Tape Standard

Complete and submit the draft tape standard developed under the ASME B89.1.7 project group to the B89.1 subcommittee for approval.

Tape Measurement Facility Upgrade

Implement the custom software and automated temperature system to improve delivery of tape calibrations.

Customer Needs

The large-part manufacturing industry is requiring ever decreasing tolerances. Many large-scale parts, even in high technology applications, lack interchangeability due to dimensional variation. For example, large commercial aircraft may require more than a ton of shims in order to complete assembly. This increase in weight can result in additional operation costs of nearly $1 M per year per plane. Furthermore, replacement parts must be custom-made since proper dimensional alignment cannot be achieved. These dimensional metrology problems result in increased component costs, operating costs, down time in maintenance due to custom fitting, and pollution.

Large-scale coordinate metrology (LSCM) is an area that can make a substantial contribution to reducing these problems associated with the inability to meet part tolerances during the part manufacture and assembly processes. By providing enhanced machine tool capability and a better understanding of in-process feedback for more accurate production and assembly, and post-process measurement for continuous process improvement it is possible to reduce or eliminate waste, rework, and low quality parts. However, this is a relatively neglected field of metrology that lacks, among other things, standards and artifacts for characterizing the metrology instrumentation and methodologies for eliciting the most out of these valuable metrology tools.

Technical Approach

Large-scale coordinate metrology problems are addressed on two major fronts in this program: (1) developing national, international, and Department of Defense (DOD) standard specifications for these coordinate metrology instruments; and (2) conducting research into performance issues and subsequent artifact development in support of these standardization efforts. Members of the Large-Scale Metrology program are actively involved on both the American National Standards Institute (ANSI) and the ISO standards developing bodies in the area of performance assessment of large-scale coordinate metrology instruments. The leadership as well as support roles they have taken on these bodies will ensure that U.S. manufacturing needs are addressed and met. The cross-participation has the byproduct of helping to unify and harmonize national and international coordinate measuring machine (CMM) standards while gaining synergy from both efforts. Additionally, NIST is leading a DOD effort to create an inter-service CMM performance standard.

In addition to the standards work, members of this program will conduct research to better quantify the error sources of these coordinate metrology systems. This will involve developing enhanced performance evaluation techniques and artifacts that will lead to a more thorough instrument characterization and more advanced methods for error elimination. For example, current research is being focused on virtual instruments. This software makes use of the instrument performance information to develop more accurate task-specific measurement uncertainty estimates through realistic measurement modeling and simulation. Also part of this effort is the Large Scale Metrology Calibration and Research Laboratory that will provide a facility to perform high accuracy calibrations and measurements.

A third area is focused on machine tool metrology for the more novel machine tool structures like the Stewart platform based hexapod machine tool. This area has three distinct objectives: develop metrology tools for characterizing machine tool tip positioning accuracy, implement on-machine metrology to enhance the positioning accuracy of the NIST Advanced Machine Tool Structure Testbed, and provide access to the metrology data base via the National Advanced Manufacturing Testbed (NAMT) environment. To achieve the first objective, we are developing and implementing a metrology system to characterize, simultaneously, the six degree-of-freedom motion of the tool tip. The second objective is long-term and considers the specific configuration of the NIST Hexapod system. The current concept is to implement a laser-based displacement measuring system to provide strut extension data. Additional critical information such as the dimensional stability of the hexapod metrology frame and the thermal behavior of the machine are being investigated using laser tracker measurements and modeling techniques, respectively.

Laser Tracker testing using a laserrail as the standard

Standards Participation

- American Society of Mechanical Engineers B89.1 Subcommittee on Length: Working Group 1.7 Surveying Tapes
- American Society of Mechanical Engineers B89.2 Subcommittee on Angles: Polygons, angle blocks, optical measurements, graduated circles, cylindrical squares, etc.
- American Society of Mechanical Engineers B89.4 Subcommittee on Coordinate Measuring Technology: Working Group 4.7 Ball Bar Systems, Working Group4.11 Probes and Probe Changers, Working Group 4.13 Interim Testing of CMMs, Working Group 4.14 Noncontact Scanning Probes, Working Group 4.19 Optical Coordinate Measurement Systems, Working Group 4.20 Artifacts Uncertainty, Working Group 4.21 CMM Performance in Realistic Environments, and Working Group 4.22 Portable CMMs
- ISO Technical Committee 172: ISO technical committee on optics and optical instruments. Subcommittee 6 Surveying Instruments
- ISO Technical Committee 213: ISO Technical Committee on dimensional and geometrical product specification and verifications. Working Group 4 Uncertainty of measurement and decision rules. Working Group 10 Coordinate measuring machines

Accomplishments

- November FY1999 Steve Phillips attended the ISO Technical Committee (TC) T13 Working Group (WG) 4 meeting held in Copenhagen November 5-6, 1998, on dimensional measurement uncertainty. Steve presented a series of issues regarding instrument specifications per ISO Standard 14253. These issues were resolved and Steve will report back to the ISO WG10 with the results as they pertain to Coordinate Measuring Machines (CMMs).

- October FY1998 Developed the framework for the virtual laser tracker, initiated commercial development of the requisite software package using the Small Business Innovation Research (SBIR) program.
- October FY1998 Participated in Advanced Technology Program 98-02 General Competition proposal evaluation.
- October FY1998 Attended several focused meetings and conferences to brief industry and to obtain their input on the role and progress of the Large-Scale Coordinate Metrology Group (LSCMG).
- October FY1998 Continued a leadership role in the development of standards for laser trackers by coordinating American Society of Mechanical Engineers (ASME) working activities, facilitating and participating at regularly scheduled meetings, and direct contributions to the writing and validation of the draft standard.
- October FY1998 Assisted U.S. industry, namely The Boeing Company, on a project to evaluate prospective measurement technologies for several critical measurement tasks. Provided test facilities, instrumentation, and test development and analysis guidance for this project.
- October FY1998 Debugged, further, the large-scale artifact calibration instrument mechanical system in an effort to reduce uncertainty levels.
- October FY1998 Began calibrating ball bars for Standard Reference Materials (SRMs) and for U.S. industry that are used in assessing coordinate metrology instrument
- October FY1998 Worked with instrument manufacturer to secure LSCMG access to emerging next generation laser tracker technologies, potentially leading to Cooperative Research and Development Agreement (CRADA).
- October FY1998 Successfully demonstrated Hexacluster metrology instrument performance both for conventional machine tools and the Hexapod.
- October FY1998 Received the Department of Commerce (DOC) Bronze Medal Award for the Hexacluster metrology instrument.
- October FY1998 Upgraded temperature system in the NIST Tape Tunnel. This area will serve as a calibration facility for long range distance measurement systems such as the laser tracker interferometric and absolute ranging subsystems.
- September FY1999 Published the following documents:
  1. "Improving Kinematic Touch Trigger Probe Performance", Quality Magazine, April 1999
  2. "A Careful Consideration of the Calibration Concept", 8th draft done, currently out for review at other NMI's.
  3. "Measurement Uncertainty and Uncorrected Bias" -- Paper and Talk, National Conference of Standards Laboratories (NCSL) proceedings
  4. "Measurement as Inference: Fundamental Ideas" - 1999 Keynote Paper in Precision Engineering and Metrology, International Organization for Production Engineering Research (CIRP); to be published in CIRP Annals, Fall 1999
  5. "Fundamental Ideas in Measurement Uncertainty," Procedures of ASPE 13th Annual Meeting, St. Louis, Oct. 1998, Vol. 18, p 311.
  6. "A Constrained Monte Carlo simulation Method for the Calculation of CMM Measurement Uncertainty," (co-author with Phillips et. al.), to be published in Precision Engineering, 1999.
  7. "A General Quantitative Method to Validate Instrument Calibration Techniques" -- a paper and talk covering new computational techniques to investigate calibration methodologies were presented at the American Society of Physical Engineering Conference. November 1999

- September FY1999 The following sites evaluated ball-step gauges either in mechanical or laser form: Hutchinson, Icamp, Balltech, Giddings & Lewis, Caterpillar, as well as the Navy and Air Force laboratories. Caterpillar extended a congratulatory letter for our efforts.
- September FY1999 Performed vibration and parametric error analysis of Hexapod platform and extended application of Hexapod metrology cluster (Hexacluster) to other measuring applications.
- September FY1999 Adapted the software developed for the large artifact calibration system to the tape calibration facility as part of calibration modernization program. Rewrote user interface and customized software for particular application.
- September FY1999 Completed extensive investigation into uncertainty sources for large-scale artifact calibration system. Completed further design enhancements on the large-scale artifact calibration instrument's mechanical system in an effort to reduce uncertainty levels.
- September FY1999 Investigated potential artifacts, designed fixturing, and conducted measurements in support of Navy CCG project on laser tracker uncertainty.
- September FY1999 Completed tasks related to phase 1 payable milestones on the Maritech "Knowledge Based Modular Repair" project.
- September FY1999 Supported the ball-bar sphere calibration work by investigating erratic measurement results.
- September FY1999 Deployed operational test system for ball-step gauge to five industrial test sites for evaluation.
- June FY1999 Participated in National Measurement Institute (NMI) key comparisons of ball-bar. Completed measurements for key comparison of ball-bar. Preliminary results indicated that the NIST machine is well within the stated measurement uncertainty of the machine. However, a full analysis of uncertainty statement is still pending.
- May FY1999 American Society of Mechanical Engineers (ASME) awarded several members of this program certificates of appreciation for service on the B89 Committee on Dimensional Metrology. The awards were signed by Richard E. Feigel - Senior Vice President, Council on Codes and Standards and Oscar J. Fisher - Vice President on Standardization.

FY2000 Measurement Services

Calibrations

- 10030C Surveying and Oil Gaging Tapes
- 10040S Special Test of Surveying Level Rods
- Special Measurement of Ball Bars

SRM

- SRM 2501 - 2509

  These are 300 mm, 400 mm, 500 mm, 600 mm, 700 mm, 800 mm, 900 mm, 1200 mm, 1500 mm Fixed Length Calibrated Ball Bars.

- SRM 2084

  CMM Probe Performance Test Standard

- SRM 2084R

  CMM Probe Performance, 10 mm sphere

- SRM 2085

  CMM Probe Performance, 20 mm sphere